Hydrocooling

NC STATE EXTENSION

Postharvest Technology Series

Most fresh fruits and vegetables require thorough cooling immediately after harvest in order to deliver the highest quality product to the consumer. Proper cooling delays the inevitable quality decline of produce and lengthens its shelf life. Most wholesale buyers now require that fresh produce items be properly and thoroughly cooled before they are shipped to market.

When warm produce is cooled directly by chilled water, the process is known as hydrocooling. Hydrocooling is an especially fast and effective way to cool produce. With modern technology, hydrocooling has now become a convenient and attractive method of postharvest cooling on a large scale.

Many types of produce respond well to hydrocooling. Produce items that have a large volume in relationship to their surface area (such as sweet corn, apples, cantaloupes, and peaches) and that are difficult to cool can be quickly and effectively hydrocooled. Unlike air cooling, no water is removed from the produce. In fact, slightly wilted produce may sometimes be revived by hydrocooling.

Hydrocooling is one of several postharvest cooling methods available to growers, packers, and shippers.

Hydrocooling:

- Cools produce rapidly (about 15 times faster than air).
- Allows for greater harvesting and marketing flexibility.
- Easily handles large amounts of produce (although hydrocoolers can also be designed for smaller quantities of produce).

There are also some limitations to using hydrocoolers:

- They can be used only for produce not sensitive to wetting. Many diseases are encouraged by wetting.
- Some hydrocoolers are not as energy efficient as other methods and therefore may not be as cost effective in some situations.
- There are some restrictions on the types of packaging and stacking arrangements used for produce that is to be hydrocooled.

This publication is intended to help growers, packers, and shippers of fresh produce make informed decisions concerning the application of hydrocooling. It discusses various types of hydrocoolers, calculation of hydrocooling rates, postharvest disease control, wastewater discharge considerations, and the energy efficiency of hydrocooling compared to other types of cooling.

About Hydrocoolers

A hydrocooler produces chilled water and then moves this water into contact with the produce. When considering a hydrocooler as a method of cooling produce, it is important to understand the water cooling methods that are used and to know the produce packaging and stacking requirements.

Caution. *Not all types of fresh produce may be successfully hydrocooled. Some are sensitive to wetting, which promotes the growth of decay organisms. For a listing of produce items that may be hydrocooled, refer to Extension publication AG 414-1,* Proper Postharvest Cooling and Handling Methods. *Of course, no matter what cooling method is employed, the produce should never be allowed to rewarm once it has been cooled.*

Hydrocooling Methods

In most hydrocoolers, a pump moves chilled water into contact with warm produce. The warmed water is then recooled and recycled. For cooling the water, many hydrocoolers have a vapor-compression refrigeration system similar to an air conditioner or refrigerator. A refrigeration system can be thought of as a pump that moves heat. The capacity of a refrigeration system to move heat is measured in tons. One ton of refrigeration is equivalent to 12,000 Btu per hour.

Some hydrocoolers do not use a refrigeration system. Instead, crushed or chunk ice is used to cool the water. Typically, large blocks of ice weighing as much as 300 pounds are trucked from an ice plant, crushed, and added as needed to a water reservoir attached to the hydrocooler. The capital cost of a hydrocooler of this type is much less than one with an integral refrigeration system and may be preferred by growers with a limited amount of produce or a short cooling season. However, to make a valid economic comparison, the cost of the ice must be considered. For a hydrocooler of this type, a reliable source of ice must be available at a reasonable cost.

Produce Packaging and Stacking Considerations

The design of the produce package and the stacking arrangement is critical to the heat transfer process in hydrocooling. A variety of produce packages have been successfully used in hydrocooling. These packages include wire-bound wooden crates, waxed fiberboard cartons, mesh poly bags, and bulk bins. Palletized packages can be hydrocooled if they are carefully stacked to allow water to enter the packages. If the water flows around and not through the packages, little cooling will occur. Produce in waxed cardboard cartons with solid tops is particularly difficult to cool because the top does not allow water to enter.

Wire-bound cartons and crates with a large percentage of open space are more suitable for hydrocooling because they allow for sufficient entry of water. Produce in 20-bushel bulk bins cools especially well because the cool water can easily percolate down through the product.

Types of Hydrocoolers

There are several different hydrocooler designs. Hydrocooling methods differ in their cooling rates and overall process efficiencies. In addition, hydrocoolers vary in the method of cooling that is used and the method of moving or placing the produce so that water comes in contact with it. Four types of hydrocoolers that are commonly used are discussed below: conventional, batch, immersion, and truck hydrocoolers.

Conventional Hydrocooler

A conventional hydrocooler allows the produce, either in bulk bins or in cartons, to pass along a conveyor under a shower of chilled water. Warm produce is placed on one end of the conveyor, and cooled produce is removed at the opposite end. The rate at which the conveyor, and thus the produce, is advanced through the shower is about 1 foot per minute and may be varied on most hydrocoolers to suit conditions. An example of a conventional hydrocooler is shown in Figure 1.

Manufacturers of conventional hydrocoolers often specify their different models by length. For example, a "10-foot" hydrocooler has an active cooling length of 10 feet, even though it may be as much as 20 feet long. The additional length is used for input and output conveyors. The longer the active cooling area, the greater the capacity of the hydrocooler. Conventional hydrocoolers with as much as 50 feet of active cooling length and a width of 8 feet have been constructed. However, specifying the capacity of a hydrocooler entirely by length can be misleading if conveyor speed, conveyor width, water temperature, and flow rate are not taken into consideration. Therefore, when comparing different hydrocoolers, buyers should find out how many pounds or bushels of a certain commodity the hydrocooler will cool per hour from one temperature to another. Most hydrocooler manufacturers can readily supply this type of data. Hydrocooling requires large quantities of water to be passed by the produce. Water flow rates as great as 20 gallons per minute per square foot of active cooling area are common. For example, a hydrocooler with an active cooling area 4 feet wide by 20 feet long (80 square feet) would require the circulation of 1,600 gallons per minute.

Most conventional hydrocoolers are high-production units with large refrigeration systems and heavy-duty components. Because of their relatively high cost, they must be operated for considerable periods each year to be economically justified. With the relatively small acreages of produce common in North Carolina, these hydrocoolers would need to be used by more than one grower (or with more than one crop) or by a co-op of growers and packers in order to be cost effective. More information on the economics of hydrocooling is given in a later section.

Batch Hydrocooler

Batch hydrocoolers are enclosures that do not have conveyors. Palletized cartons or bulk bins of produce are loaded into the enclosure with a fork lift. The door of the enclosure is then closed, and large quantities of chilled water are flooded over the top of the produce, collected at the bottom, recooled, and recycled.

Most batch hydrocoolers can cool only one pallet of produce at a time, as shown in Figure 2. However, some larger batch units are occasionally built that can cool as many as eight pallets at once. These hydrocoolers generally have a smaller capacity than conventional hydrocoolers and therefore may be less expensive. They are better suited to growers with a limited amount of produce that could not economically justify a larger unit.

A frequent complaint about both conventional and batch hydrocoolers is that they do not cool all containers uniformly. The chilled water may not be evenly distributed throughout the load, resulting in undercooling of some parts. To overcome this deficiency, some batch hydrocoolers use a high-capacity fan to pull a fine mist of chilled water through the produce packages. The forced air has the effect of making the cooling more consistent because it pulls the water past the produce more evenly than would occur by gravity flow alone. This design, known as "hydro-air-cooling," has been successfully used with items that are particularly difficult to cool. Figure 3 shows a typical hydro-air-cooling unit.

Immersion Hydrocooler

Immersion hydrocoolers are large, shallow, rectangular tanks that hold moving chilled water. Crates or boxes of warm produce are loaded into one end of the tank and moved by a submerged conveyor to the other end where they are removed. Crushed ice or a vapor-compression refrigeration system keeps the water cold, and a pump keeps the water in motion. Most produce is only slightly buoyant so it tends to stay submerged. The length of time the produce remains in the water varies with the initial conditions and desired ending temperature. Figure 4 shows an immersion hydrocooler loaded with wire-bound crates of sweet corn.

Test have shown that the most rapid hydrocooling is obtained by immersing produce in tanks of agitated chilled water. Immersion hydrocooling is nearly twice as rapid as conventional hydrocooling methods. With conventional hydrocooling, the cold water that is sprayed or flooded over the produce contacts only a portion of its surface. The result is less than maximum heat transfer. Immersion hydrocooling reduces the temperature more rapidly because moving chilled water completely surrounds the exterior surface.

Immersion hydrocooling was once practiced by placing loose produce into tanks of chilled water. This method is seldom practiced today because it is labor intensive and much of the cooling effect is lost when the produce is packed. In addition, packing shed workers are often reluctant to handle the wet, cold produce. The bulk "fluming" of string beans in chilled water prior to grading and packing is an example of immersion hydrocooling. Bean fluming is gradually being replaced by other hydrocooling methods.

Truck Hydrocooler

Some sweet corn growers in North Carolina use a cooling method known as "truck hydrocooling." In this process, water is cooled and delivered to the produce by a simple system consisting of a tank holding several thousand gallons of water, a high-capacity pump, associated piping and valves, and an ice crusher. Graded and packaged produce (as much as 600 to 800 crates) is loaded from the field into a tractor trailer. Perforated pipes are then inserted into the trailer above the load to deliver a shower of chilled water from the stationary cooling system (Figure 5). The water flowing out of the trailer is collected, recooled, and recycled. Water flow rates of 1,000 gallons per minute for this type of hydrocooler are common. After an hour or more of hydrocooling, the pipes are withdrawn, a layer of crushed ice is added over the top of the crates, and the produce is immediately shipped.

To cool the water, blocks of ice from a commercial ice plant are crushed and added to the tank. Approximately one 300-pound block of ice is required per 100 gallons to cool the water initially. As the water warms during the cooling process, ice is added periodically.

Truck hydrocoolers can be built by the grower at a central location on his or her farm for a small fraction of the cost of a commercial hydrocooler. A truck hydrocooling system capable of cooling several truckloads of fresh produce per day can be built from locally available parts.

Until recently, it was assumed that truck hydrocooling removed 30 to 40 degrees of field heat from sweet corn cooled in this manner. However, recent tests conducted at several locations in eastern North Carolina have not supported this common belief. Temperature sensors positioned throughout a trailer load of sweet corn hydrocooled for 1 hour and 45 minutes showed an average decline in temperature of only 15°F. This poor cooling rate apparently occurs because most of the water flows through the spaces between the crates, decreasing the total heat transfer.

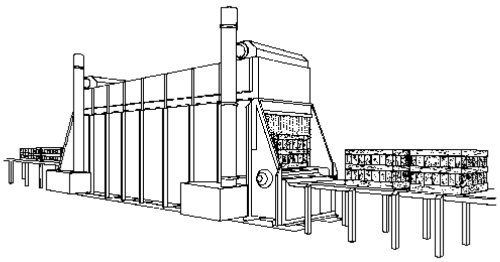

Figure 1. Typical conventional hydrocooler.

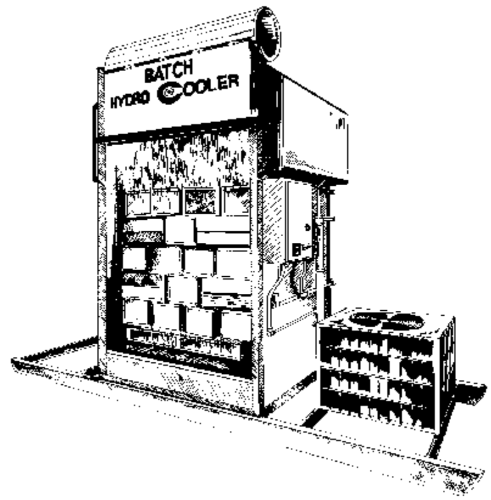

Figure 2. Single pallet batch cooler.

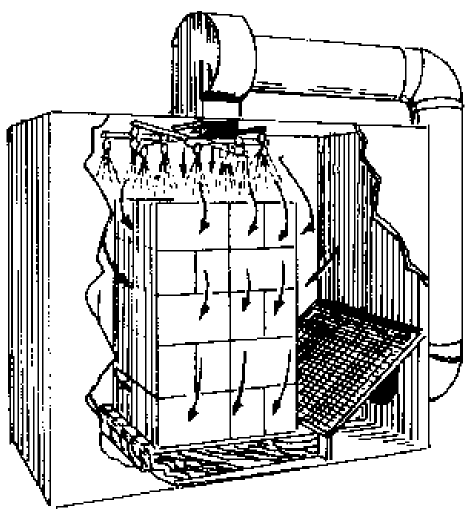

Figure 3. Cut-away view of a hydro-air-cooling hydrocooler.

Figure 4. Immersion hydrocooler.

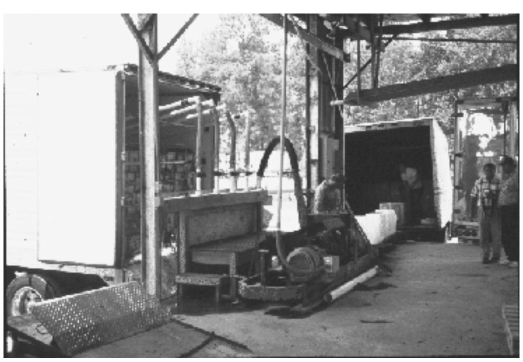

Figure 5. Truck hydrocooling operation in Eastern North Carolina.

Determining Hydrocooling Rates

To operate a hydrocooler effectively and efficiently, it is necessary to understand how water removes heat from the produce and the factors that affect the rate of cooling for various types of produce. The next section provides a fundamental description of these points and how to calculate approximate hydrocooling rates for various fruits and vegetables. For more precise estimates and information, consult a hydrocooler manufacturer or your county Extension agent.

Heat Transfer

When any object is warmed or cooled, the physical process is known as heat transfer. There are several different mechanisms of heat transfer. In the process of hydrocooling, the heat in the produce is carried away by the currents of moving water. This type of heat transfer is known as convection. Several factors contribute to the rate at which heat is transferred during convection. One of these factors, called the heat transfer coefficient, remains nearly constant for all types of produce. The heat transfer coefficient is a measure of how fast heat is transferred from the surface of an object. A commonly used value for the heat transfer coefficient is 120 Btu per hour per square foot per degree Fahrenheit. The equation for convection is shown in the box below.

The basic heat transfer equation governing convection is:

Q = h x A x (Ts - Tw)

where:
Q = the rate at which heat is transferred from a batch of produce, in units of Btu/hr
h = the heat transfer coefficient, in units of Btu/(hr ft^2 °F)
A = the total exposed surface area of the produce, in square feet, over which the heat transfer occurs
Tw = the temperature of the water (°F)
Ts = the temperature of the produce surface (°F)

From the equation, it may be seen that the rate of heat transfer, Q, is directly proportional to the magnitude of the heat transfer coefficient, the amount of surface area, and the temperature difference between the surface of the produce and the water.

Other factors also affect the rate of heat transfer, including the surface area of the produce and the temperature difference between the surface of the produce and the chilled water. These factors relate directly to the time it takes to cool a specific type of produce. This means that the rate of heat transfer for produce increases when the surface area of the produce increases or when the difference between the produce temperature and the water temperature increases.

The surface area that is exposed to the chilled water varies considerably among different types of produce. For example, the surface area of 10 pounds of sweet corn is considerably less than that of 10 pounds of snap beans. Therefore, if hydrocooled in water of the same temperature, snap beans can be expected to cool much faster than sweet corn. In addition, the greater the difference between the water and the produce temperature, the faster the cooling.

So far, the discussion has centered on heat transfer from the standpoint of the surface temperature of produce. When cooling produce, the rate of cooling of the interior of the produce is of primary importance. The theoretical basis just reviewed will promote a better understanding of the factors that affect the hydrocooling rates of various produce and hydrocoolers.

Calculating Cooling Rates

Field and laboratory studies have provided useful data on hydrocooling rates for many fruits and vegetables. This information can be used to calculate how long it takes to cool the interior of a particular product to a desired temperature if the starting temperature and the water temperature are known.

To calculate the cooling rates for different types of produce and other types of hydrocoolers, refer to the instructions in the box below.

Researchers have developed a graph summarizing current information about heat transfer for various fruits and vegetables. Presented in Figure 6, this graph shows a family of eight ideal cooling lines for various types of produce immersed in agitated chilled water.

Figure 6 KEY:
A – Greens
B – Beans, peas, asparagus
C – Small cucumbers, radishes, beets (< 1.5" dia.)
D – Small apples and peaches, slicing cucumbers
E – Sweet corn, apples, and peaches
F – Large apples and peaches (> 3" dia.)
G – Cantaloupes, large eggplant

These lines are approximations only and are based primarily on the physical size of the produce. The horizontal axis is the cooling time in minutes and the vertical axis is the decimal temperature difference **(DTD)** at the temperature you want to reach. To calculate the hydrocooling time for a specific type of produce, use this equation for DTD:

DTD **=** (T **-** W) ÷ (P **-** W)

where:
T = the target temperature (°F)
W = the temperature of the water (°F)
P = the starting temperature of the produce (°F)

Follow the steps in the example below to calculate the hydrocooling time for sweet corn.

Example: Sweet corn, with a center cob temperature of 85°F, is to be hydrocooled by immersion in 35°F water. How long will it take to reduce the center cob temperature to 55°F?

Figure 6 must first be consulted to locate the cooling line (E) that applies to sweet corn. DTD is then calculated by using the above equation:

DTD **=** (55 **-** 35) ÷ (85 **-** 35) **=** 0.4

By finding the place on Figure 6 where curve E intersects the DTD = 0.4 line and projecting downward to the X-axis, you will see that the time required to cool the sweet corn from 85°F to 55°F is approximately 28 minutes. Suppose the packer was considering cooling the corn not to 55°F but to 42°F. In this case the DTD would be:

DTD **=** (42 **-** 35) ÷ (85 **-** 35) **=** 0.14

Again, by finding the place on Figure 6 where curve E intersects the DTD = 0.14 line and projecting downward to the X-axis, the time required to cool the sweet corn from 85°F to 42°F is found to be approximately 56 minutes.

In the example above, it was assumed that the individual ears of corn were completely immersed in agitated, chilled water. Recall that immersion is the fastest possible hydrocooling method. When the sweet corn is totally immersed, all outside surfaces are covered with cold water. If the sweet corn were hydrocooled in a conventional hydrocooler or closely packed in a wire-bound crate with other ears of corn, the cooling time would be considerably longer. Data published by the manufacturers of conventional hydrocoolers suggest that cooling times for their equipment be estimated at 40 to 80 percent longer than for immersion hydrocooling. The cooling time for sweet corn on a conventional hydrocooler can be estimated by multiplying the immersion hydrocooler rate by a conversion factor of 1.5:

28 minutes (immersion hydrocooling rate) **x** 1.5 (conversion factor) **=** 42 minutes (conventional hydrocooling rate)

Figure 6 should be used as a rough guide only. Consult a hydrocooler manufacturer for more precise hydrocooling rates.

Figure 7 shows the cooling curve for sweet corn with a starting temperature of 85°F and a cooling water temperature of 35°F. Note that the cooling proceeds rapidly at first but then slows as the produce temperature approaches that of the chilled water. It takes 28 minutes to cool the corn 30 degrees (from 85°F to 55°F), but it takes twice that long to cool it another 13 degrees (from 55°F to 42°F). The graph illustrates that hydrocooling is much more efficient at removing the first 30 degrees or so of heat from the produce. Attempts to reduce the heat further by hydrocooling may result in decreased productivity and increased cooling costs. Alternate cooling methods, such as top icing, may be more practical if additional cooling is desired.

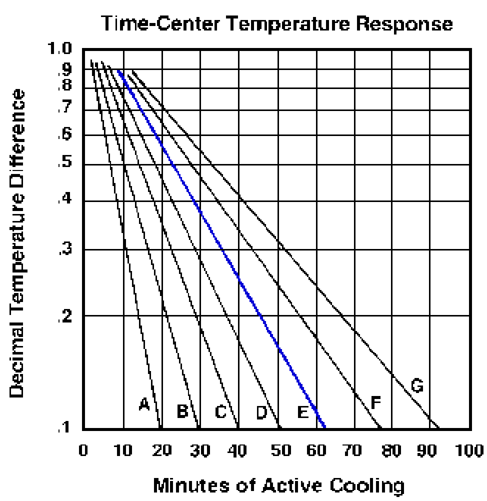

Figure 6. Time-temperature response of various fruits and vegetables immersed in agitated chilled water. Refer to the box for the KEY.

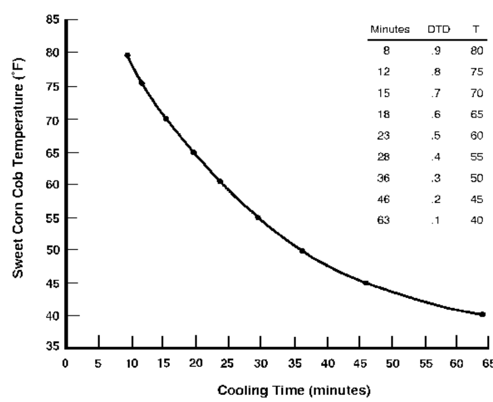

Figure 7. Example of cooling rate for sweet corn.

Chlorination, Disease Control, and Wastewater Quality

Although hydrocooling is an excellent cooling method, it does wet the produce. The surface of warm, wet produce provides an excellent site for postharvest diseases. Therefore, it is essential that once hydrocooled, produce should not be allowed to rewarm. Produce is particularly susceptible to postharvest diseases when it is stressed by too much or too little water, high rates of nitrogen, or mechanical injury (scrapes, bruises, or abrasions). Also, since the hydrocooling water is recirculated, it can spread disease from a few infected items to all the produce hydrocooled thereafter. To reduce the spread of postharvest diseases, the *North Carolina Agricultural Chemicals Manual* recommends the use of chlorine as a disinfectant at the rate of 55 to 70 parts per million. Chlorine for use in hydrocooling water can be purchased in the form of a sodium hypochlorite solution (for example, Clorox) or as dry, powdered calcium hypochlorite.

Several factors affect the amount of chlorine available in the hydrocooling water over time. Chlorine used in hydrocooling water is quite volatile and will disperse into the air at a rate that increases with the temperature of the water. The warmer the water, the faster the chlorine will leave the solution. Furthermore, chlorine tends to attach to soil particles. Thus, dirty produce uses up the available chlorine much faster than relatively clean produce.

In addition to the factors discussed above, the pH of the water has a significant effect on the availability of chlorine. Even if a normally sufficient amount of chlorine is added to the hydrocooling water, the chlorine may not be available in a usable form if that water is acid (below a pH of 6.5) or basic (above a pH of 7.5). For the chlorine to be optimally available, the pH of the hydrocooling water should be nearly neutral (pH of 7.0). Over seven times more chlorine is needed to disinfect at a pH of 8.5 than at a pH of 7.0.

Because the pH of well water in North Carolina varies from moderately acid to moderately basic, it is a good idea to check the water with a pH meter or test papers. Even if your water has a nearly neutral pH, the addition of hypochlorites will cause the water to become basic. Therefore, adding a small amount of common acids like lemon juice or vinegar may be necessary to correct the pH. Inexpensive test papers for checking both the chlorine level and pH may be obtained from most swimming pool and chemical supply houses.

Pathogenic (disease-causing) organisms may enter the hydrocooling water both in the active vegetative form and in the form of spores. The chlorine will quickly kill the vegetative form, but the spores are 10 to 1,000 times more difficult to kill. Therefore, chlorine treatment does not usually eliminate all pathogens and sterilize the surfaces of the produce. Many spores may remain on the surface to develop later if the opportunity arises (that is, if the produce is allowed to rewarm). The effectiveness of the chlorine treatment depends on the length of exposure. Fortunately, the long exposure that is common with hydrocooling is much more effective than a quick dip treatment. However, chlorination is only a surface treatment. If the pathogens have already started to develop below the surface, chlorine will be ineffective. Also, chlorine solutions can produce surface bleaching.

The wastewater from hydrocooling is usually dumped at the end of each workday or more often if necessary. This wastewater often contains high concentrations of sediment, pesticides, and other suspended matter. Hydrocooler water may be considered an industrial wastewater if the product is discharged to a municipal wastewater treatment plant or to surface waters (canals, creeks, or ponds). Land application of this material is normally permitted, but a nondischarge permit may be required. A hydrocooler owner may be required to obtain a wastewater discharge permit.

Anyone using or planning to use a hydrocooler should check with the local office of the North Carolina Department of Environment, Health, and Natural Resources to determine whether a permit is required. The illegal disposal of hydrocooler wastewater may result in a substantial fine.

Energy Efficiency

Well-designed and properly operated hydrocoolers have the advantage of being able to cool large amounts of produce in a short period of time. However, many commercial and most homemade hydrocoolers are not very energy efficient. Studies have shown that conventional and batch hydrocoolers can waste as much as one half the total energy input. Truck hydrocoolers can be even less energy efficient and may waste as much as 85 percent of the energy input. This is because water contacts the truck body and surrounding areas, substantially increasing the amount of heat entering the water.

During hydrocooling, much of the energy loss occurs because the falling water gains heat from the air. Energy loss also results from the lack of insulation on refrigerated surfaces. Additional losses occur if a hydrocooler is operated at less than full capacity, if it is operated intermittently, or if more water than necessary is used.

Immersion hydrocoolers are the most energy-efficient type of hydrocooler because the water-to-air contact is minimized. A well-designed immersion hydrocooler may have an energy efficiency as great as 70 percent.

Energy use in hydrocoolers may be substantially reduced by:

- Using generous amounts of insulation on all refrigerated surfaces and positioning the hydrocooler out of the wind and sunlight.
- Using plastic strips on both the inlet and outlet ends of conveyor hydrocoolers to reduce the water-to-air heat gain.
- Operating the hydrocooler at maximum capacity. Intermittent operation wastes energy, as does operation at reduced capacity. A low-capacity hydrocooler operated for long periods is more energy efficient and economical than a high-capacity unit operated for shorter periods. Some hydrocoolers may now be purchased with a thermal storage option. Thermal storage capacity not only reduces the size of the refrigeration unit necessary but may also result in a smaller energy bill.
- Using an appropriate-size water reservoir. An oversized water reservoir wastes energy because the remaining cooling capacity of the water is lost when it is dumped at the end of the day.

Economics

For those products that can tolerate wetting, hydrocooling may be the best cooling method. However, for those contemplating hydrocooling, the basic question is: Can I afford to hydrocool? The answer depends upon an accurate comparison of both the costs and the benefits of hydrocooling.

Costs

The costs of a hydrocooler include the amount of money needed to purchase, install, and operate the system. These costs may be separated into two categories: (1) annual fixed costs and (2) annual variable (operating) costs.

Annual Fixed Costs. These are expenses that will be incurred whether the hydrocooler is used or not. They include expenses for depreciation, insurance, interest on money borrowed to buy the equipment, and taxes. Typically, annual fixed costs for hydrocoolers are substantial because of the high cost of the refrigeration unit and all associated equipment. A standard commercial-size conveyor hydrocooler capable of cooling 10,000 pounds of produce per hour may cost more than $125,000. More modest units or farm-built systems can reduce the investment costs, but costs are likely to remain substantial. Average annual fixed costs per unit of product hydrocooled decrease as the amount of produce hydrocooled increases; that is, as more product is cooled, the average annual fixed cost per unit declines.

Annual Variable Costs. These expenses vary directly with the amount of produce hydrocooled. Variable costs include wages paid to laborers to load and unload the hydrocooler unit, operate and maintain the hydrocooler, and make repairs. They also include costs of maintenance supplies, water, and electrical power. Block ice used as a source of cooling is another variable cost. While total variable costs increase as the volume of product cooled increases, the variable cost per unit of produce hydrocooled remains approximately constant.

The total cost per unit of product hydrocooled is the sum of both the annual fixed costs and the annual variable costs. When the total cost is divided by the number of units hydrocooled, the result is the average cost per unit of produce hydrocooled.

Benefits

There are both tangible and intangible benefits to hydrocooling. The greatest tangible benefit is any price premium received for hydrocooled produce. Whether a price premium will be received depends on the type of produce, the market conditions, and the end use. For example, buyers from distant markets may be more willing to pay extra for cooling, whereas local buyers may not. Also, fresh markets may be more willing to pay for cooling than processing markets.

Intangible benefits, although harder to define, are just as important. These benefits include added harvesting and marketing flexibility, reduced losses in transit, and the pride that comes with shipping a quality product. In times when there is more produce than the market can accept, produce that has been properly hydrocooled will hold a clear market advantage over produce that has not.

For hydrocooling to be economically viable, the average cost per unit of produce cooled must be less than the sum of the benefits expected. Given the high initial costs and operating expenses, usually only large-scale producers and handlers (those producing on several hundred acres or more) find hydrocooling to be economically viable. However, growers and handlers with moderate acreage have explored several ways to reduce initial investment and variable costs. One option is to lease hydrocooling equipment. Another option is to increase the volume of produce hydrocooled by increasing the diversity of crops planted or staggering planting periods to expand the length of the harvest season. These options increase the amount of produce hydrocooled, thus reducing the average annual fixed cost and the total cost of cooling. Finally, a group of growers and shippers may jointly purchase or lease portable hydrocooling equipment.

For More Information

Other methods of cooling produce are also available, such as room cooling, forced-air cooling, top icing, vacuum cooling, and evaporation cooling. For more information on these and related topics, refer to other publications in this series, *Maintaining the Quality of North Carolina Fresh Produce*:

AG 414-1, *Proper Postharvest Cooling and Handling Methods*
AG 414-2, *Design of Room Cooling Facilities: Structural and Energy Requirements*
AG 414-3, *Forced-Air Cooling*
AG 414-5, *Crushed and Liquid Ice Cooling*
AG 414-6, *Chlorination and Postharvest Disease Control*

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